THE EFFECTS OF SLUDGE FERTILIZATION, ACCESS TRAIL, SPECIES, INITIAL DIAMETER, DENSITY, CROWN AND VIGOR CLASSES ON GROWTH OF INDIVIDUAL OAK TREES AND THEIR RELATIONS TO WATERSHED MANAGEMENT*)

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ABSTRAK

Tujuan utama dari tulisan ini adalah menganalisis hubungan antara pertumbuhan individu pohon dengan perlakuan yang meliputi pemupukan dengan air limbah dan jalur akses, kerapatan, spesies pohon, kelas tajuk, dan kelas ketegaran pohon. Tujuan yang ke dua adalah mengambil manfaat hasil analisis tersebut untuk meningkatkan produktivitas dan pengelolaan lahan hutan dan lingkungan sebagai bagian dari sasaran pengelolaan daerah aliran sungai (P-DAS).

Sembilan plot berukuran masing-masing 1,51 ha. secara random ditunjuk untuk 3 perlakuan yaitu 3 plot kontrol, 3 plot untuk perlakuan jalan akses, dan 3 plot untuk perlakuan jalan akses + air limbah. Sebanyak 1116 pohon diukur diameternya, didata kelas tajuk, kelas ketegarannya, dan nama spesiesnya untuk dianalisis. Metode statistik yang digunakan untuk analisis adalah *multivariate analysis*.

Hasil penelitian menunjukkan bahwa dalam waktu 12 tahun air limbah dapat memacu pertumbuhan bidang dasar pohon sebesar 15,53 cm^2, dan jalur akses memacu pertumbuhan bidang dasar pohon yaitu untuk sisi sebelah timur sebesar 7,41 cm^2 dan sebelah barat sebesar 12,32 cm^2. Pohon yang lebih tegar akan tumbuh lebih cepat, kelas tajuk yang lebih tinggi akan tumbuh lebih cepat, kerapatan pohon yang lebih tinggi akan lebih menghambat pertumbuhan pohon, pohon dengan diameter awal yang lebih besar akan tumbuh lebih cepat, *Acer rubrum* tumbuh 29,96 cm^2 lebih cepat dari pada *Quercus rubra* dan 24,74 cm^2 lebih cepat dari pada *Quercus alba*, sementara *Quercus rubra* tumbuh 5,12 cm^2 lebih cepat dari pada *Quercus alba*. Hasil-hasil ini merupakan dasar pijakan yang sangat berarti untuk peningkatan pengelolaan lahan hutan dan lingkungan sebagai bagian dari sasaran P-DAS.

Kata-kata kunci: pertumbuhan individu pohon, jalan akses, air limbah, *multivariate analysis*.

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INTRODUCTION

Studies on average tree growth or stand growth of various forests have been conducted at many sites or locations by foresters. However, only few studies on individual tree growth results of mixed forest have been reported. The average tree growth reported are related to average or cumulative growth of many trees growing in an area; consequently factors such as density, crown classes, vigor classes, and differences of single species can not be taken into analysis. The assessment of individual tree growth on the other hand would find out the effects of treatments, i.e. density in terms of basal area and number of trees per hectare, crown classes, and vigor classes on tree growth, and growth differences of each species. It is for those reasons this study is conducted on the basis of individual tree growth analysis .

The study site is located in Montmorency county at the Atlanta Forest Area of the Mackinaw State Forest, Northern Michigan, USA. In 1981, when the study was initiated, several species of oak trees were 70 years old. The trees consisted primarily of red oak (*Quercus rubra* L.), black oak (*Quercus velutina*), white oak (*Quercus alba*) and red maple (*Acer rubrum* L.); with scattered pines (*Pinus* spp.) and aspen (*Populus* spp.). Soils at this site were dominantly mapped as the deep, somewhat excessively drained Graycalm soil series. Depth to groundwater was in excess of 25 m (Hart *et al.*, 1986).

In October and November 1981 this oak site was treated with 264,971 liters of Alpena wastewater sludge for plot 1, and 514,801 liters Rogers City wastewater sludge for plots 5 and 7 out of 9 studied plots.

Objectives

The first set of the objectives of this study were to: remeasure and analyze the growth of individual trees; to determine growth equation and discuss individual tree basal-area growth in relationship to (1) treatments consisting of sludge and access trail effects, (2) density in terms of basal area and number of trees per hectare, (3) species, (4) crown classes, and (5) vigor classes. The growth responses were analyzed for the twelve year response period from 1981 to 1993. The other objective of this study was to see the silviculture and watershed management impact of the results of the first objective.

LITERATURE REVIEW

Sludge Fertilization in Relation to Growth of Trees

The application of municipal sludge has been successfully practiced for many years and has proved to be an effective fertilizer and soil conditioner when applied to forest lands and tree species (Henry, 1986). As a fertilizer, the sludge provides the forest ecosystem with nutrients that enhance vegetation growth. The properly applied and monitored treatment of municipal sewage sludge to forests and degraded lands can physically, chemically, and biologically rehabilitate the lands (Marx *et al.*, 1995).

Access Trails in Relation to Growth of Trees

Winston (1977) said that strip (row) thinning in semimature jack pine was found to yield larger residual trees and slightly greater net merchantable volume increment after the four-year response period. One may hypothesize that the trails (cut row) release room for the trees in the outer portions of the uncut strips to expand their crowns and root systems and this will allow the trees to secure large supplies of nutrients. Also after several years of thinning responses the actual crown surface exposed to direct sunlight is greater than on trees in the inner portions of the uncut strips, making possible even greater growth.

Species, Density, Crown Classes and Vigor Classes in Relation to Growth of Trees

Trimbel (1969) in the study of diameter growth of individual hardwood trees discussed diameter at breast height (dbh) growth in relationship to: (1) crown and vigor classes, (2) crown measurements, (3) initial dbh, (4) basal-area density, and (5) species and site quality. He claimed that correlation between dbh growth rates to crown classes and vigor classes were both ranked in logical order. Trimble said if dbh was related to initial dbh, on the average, the larger trees grew faster in diameter than the smaller trees. He also indicated that there was a strong relationship existed between dbh growth, species and site quality.

Nichols and Carvell (1987) studied growth responses of individual trees of Appalachian Hardwoods to various degrees of release. They grouped trees by species, crown classes and treatment. They concluded that white oak (*Q. alba*), northern red oak (*Q. rubra)*, and red maple (*A. rubrum*) increased their basal area growth quickly when released. Yellow poplar (*Liriodendron tulipifera*) and chesnut oak (*Q. montana)* did not response.

Hannah (1985) studied response of yellow birch (*Betula alleghaniensis*) and sugar maple (*A. saccharum*) to fertilizers (N, P, K, and lime) on four forest sites in Vermont. He grouped trees by species, treatments, and crown classes. Growth responses were tested using analysis of variance with original tree diameter used as a covariable to adjust for differences in tree size. He concluded that small yellow birch and sugar maple pole size trees 10 to 18 cm dbh did not respond to fertilizers for 14 years. He went on to say that improved growth was best related to crown size.

Watershed Management Relations

Generation of wastewater sludge in the United States has become a problem of *increasing proportion*, with annual production at 4 million tons in 1970 (Wals, 1976) and 7 million tons in 1987 (Maness, 1987). This wastewater sludge represent a major waste by-product from society that must be managed in responsible ways, and not released into aquatic systems or allowed to contaminate ground waters (Henry *et al.*, 1993). Brooks *et al.* (1992) said that the use of forest-land as secondary treatment system for wastewater was one kind of watershed management practice in developing solution to natural resource problems.

A research conducted in Michigan showed that sludge substantially enhanced nutrient cycling, tree growth, wildlife habitat, and nutritional quality of forage plants in the forest. At appropriate application rates, these benefits were obtained while avoiding groundwater contamination and toxicant transmission in food chain (Hart *et al.*, 1988).

So, forest-land application of wastewater sludge is promising an important watershed management practice that addresses not only benefit tree growth and wildlife habitat but also highlight the need of environmental protection.

MATERIALS AND METHOD

Experimental Design

The experimental treatment plots were 1.51 ha in area of rectangular or square to allow positioning the plots in usable areas with minimum buffer zones of 15.25 m between plots. Nine plots were assigned randomly for three treatments with three replicates. The treatments were control (C), access trails (T), and trail + sludge (TS).

Parallel trails at approximately 20 m intervals were used for trail and trail + sludge treatment plots. The trails for the trail + sludge plots were prepared to facilitate vehicle access to apply more uniform sludge distribution. Five measurement subplots were defined for each plot. To study edge effects of application trails, the measurement subplots were divided into three zone plots, east zone (Te), center zone (Tc), and west zone (Tw).

Data Measurement

The following measurements taken in 1981 and 1993 at the oak trees site were used: (1) diameter at breast height (DBH: 1.37 m), (2) areas of measurement zones, (3) crown class (dominant, codominant, intermediate and suppressed), and (4) condition (vigorous, fair, and weak or stressed).

Crown Classes

According to Daniel *et al.* (1979) tree crown classification in the United State has five classes: dominant, codominant, intermediate, suppressed, and dead trees. Four crown classes have been adopted and developed for use in this research:

1. *Dominant Trees.* The crowns of dominant trees rise somewhat above the general level of the canopy so that they are exposed to full light above and, to a certain degree, laterally larger than the average trees in the stand, and with crowns well developed but possibly somewhat crowded on lateral side.
2. *Codominant Trees.* Trees with crowns forming the general level of the crown cover and receiving full light from above but comparatively little from lateral sides; usually with medium-sized crowns more or less crowded on lateral sides.
3. *Intermediate Trees.* These crowns occupy definitely subordinate position and are subjected to sharp lateral competition from crowns of the two previous classes, although they receive some direct overhead light through holes in the canopy.
4. *Suppressed Trees.* These are definitely overtopped members of the forest community having almost no free overhead light. They exist by virtue of sunlight that filters through the canopy or skylight that may be received through some chance opening.

Vigor Classes

Tree vigor classes have been used successfully to predict diameter growth rates for hardwood species (Trimbel, 1969). In the development of vigor classifications, emphasis has been placed on crown features such as size and relative health and bark characteristics (Hart *et. al.*, 1986). Four vigor classes have been adopted for use in this research. The four vigor classes are as follows :

1. *Vigorous Trees.* A tree with large, healthy, and full crown. The crown is dense, with no evidence of disease or injury. The bark and twigs have good color and vigorous appearance.
2. *Fair Trees.* A tree with fair-sized crown. The crown is less dense and not so perfect as that of vigorous tree. This class may also include large-crowned tree that fails to meet the requirements of vigorous tree because of mechanical injury or dying limbs.
3. *Weak Trees.* A tree with small to medium crown. The crown may be open, with some dead or broken limbs, or thinly foliated. This class may also include trees with fair to large crowns but can not meet the requirements for those mentioned above.
4. *Mortality Trees.* This class includes all trees that have just died.

Growth

Tree basal area was calculated during period of 1981 and 1993 and the basal area growth (BAG) was calculated by subtraction. Trees undergoing mortality between 1981 and 1993 were excluded from the analysis.

Statistical Analysis Method

The statistical method used to analyze the data was multivariate analysis with cross classification and multiple covariates in unbalanced models. The primary variables to be analyzed were tree basal-area growth responses (BAG).

The first factor (or categorical variable) was sludge with two levels. S1 was sludge treatment and S0 was without sludge treatment. The second factor was zone with three levels. TW was west zone, TE was east zone, and TO was center zone. All trees from the control plots having no trail access were assigned TO. The third factor was vigor class with three levels: vigorous trees (VIG), fair trees (FAIR), and weak trees (WEAK). The fourth factor was crown class with four levels: dominant (DOM), codominant (CODOM), intermediate (INT) and suppressed (SUP). The fifth factor was species with three levels: red maple (RM), red oak (RO), and white oak (WO).

The covariates or quantitative variables were the initial tree diameter (D81), initial number of trees in the zone (ZNT81), and the initial zone basal area (ZBA81).

The general regression model was :

$$\mathbf{Y_i = b_j X_{ij} + E_i} \textbf{ (Gill, 1993)}$$

where :

Y	=	tree BAG response
b	=	matrix of parameters estimated by the model
X	=	matrix of independent regression variables
i	=	1, 2, 3, 4, ..., the numbers of trees
j	=	1, 2, 3, ..., 14 parameters.

The parameters may be subdivided into b_1 (origin of regression), $\{b_2\}$ for sludge (S1, S0) effects, $\{b_3, b_4\}$ for Zones (TW, TE, TO), $\{b_5, b_6\}$ for vigor classes (VIG, FAIR, WEAK), $\{b_7, b_8, b_9\}$ for crown classes (DOM, CODOM, INT, SUP), $\{b_{10}, b_{11}\}$ for species (RM, RO, WO), b_{12} effect of initial diameter, b_{13} effect of initial plot basal area, and b_{14} effect of initial number of trees in the zone. The independent variables, $X_1 = 1$ for all trees, $X_2, X_3, ...X_{11}$ are dummy variables (USDA Forest Service, 1964) taking value 1 (if a particular tree was represented in a certain factor) or zero (otherwise). Only X_{12}, X_{13}, and X_{14} are measured variables (initial diameter (D81) in mm, initial zone basal area (ZBA81) in cm2/ha, and initial number of trees in the zone (ZNT81)).

The data was analyzed with the microcomputer SYSTAT program (Systat Inc., 1992). Analysis of variance header printouts include: dependent variable (*DEP VAR*) for tree diameter growth or basal-area growth, number of tress analyzed (*N*), and coefficient of multiple correlation (*R*) among dependent variable with independent variables. The table data includes sources of variances and their attributes including the estimate of the regression coefficient, the standard error of the coefficient, tolerance for detecting intercorrelation among the predictor variables, t statistic for measuring the usefulness of the variable in the model, and significance test level for t. Information at the bottom is an analysis of variance table testing the overall regression.

The analysis for each growth measure was performed two times. Exploratory analysis was performed with all possible independent variables involved. The second regression analysis was conducted using the Stepwise Option. Results reported are based on the stepwise derived equation with significant variables.

RESULTS AND DISCUSSIONS

Analysis of variance for tree basal-area growth responses (BAG) of individual trees at the oak site with all possible independent variables showed that the contribution of initial zone basal area ZBA81 to the estimated BAG could be neglected. Table 1 showed the results of the analysis omitting the ZBA81. The analysis resulted in coefficient of multiple correlation ($R=0.828$), high values of tolerances meaning that the predictor variables were not intercorrelated, and the regression among the variables was significant (p-value < 0.000).

Growth Related to Sludge Treatment

Table 1 showed that during the period of 1981 - 1993, sludge have significant effect on tree BAG. Over twelve years sludge treatment increased tree BAG by 15.67 cm^2 compared to similar non sludged trees.

The sludge treatment at the oak site resulted in an average of 401 kg/ha loading rates of nitrogen and 272 kg/ha loading rates of phosphorus (Hart *et al.*, 1986), the elements most often deficient in soils. Those nutrients, and other nutrients the sludge contained apparently caused significant effect on the tree BAG.

Growth Related to Zone Effects

Table 1 showed that during the period of 1981 - 1993, edges (TW and TE) performed a significant effect on tree BAG. The BAG were higher in west and east zones (in the trail and sludge plots) than in the center zone or in the control plots. Over twelve years, west zone (TW) near access trail performed 12.23 cm^2 greater BAG. East zone (TE) near access trail had 7.40 cm^2 greater BAG.

Table 1. Basal area growth response (BAG) of individual trees at oak site with indicator variables by omitting non significant variables

DEPVAR:	BAG13	N: 1116	MULTIPLE R: 0.828		
VARIABLE	**COEFFICIENT**	**STD ERROR**	**TOLERANCE**	**T**	**P(2 TAIL)**
CONSTANT	-79.75	6.88		-11.58	0.00
S1	15.67	2.00	0.90	7.85	0.00
TW	12.23	2.24	0.87	5.45	0.00
TE	7.40	2.28	0.86	3.25	0.00
VIG	49.58	5.98	0.20	8.30	0.00
FAIR	26.71	5.24	0.21	5.10	0.00
DOM	29.38	3.01	0.67	9.77	0.00
INT	-7.51	2.06	0.86	-3.66	0.00
D81	0.60	0.02	0.48	25.25	0.00
ZNT81	-0.01	0.00	0.92	-3.02	0.00
RM	29.96	2.38	0.58	12.58	0.00
RO	5.17	2.31	0.63	2.24	0.03

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	2053732.517	11	186702.956	218.582	0.000
RESIDUAL	942985.463	1104	854.153		

To estimate BAG, we may use the equation derived from Table 1 as follows :
BAG (cm^2) = - 79.75 + 15.67S1 + 12.23TW + 7.40TE + 49.58VIG + 26.71FAIR + 29.38DOM - 7.51INT + 0.60D81 - 0.01ZNT81 + 29.96RM + 5.174RO
The S1, TW, TE, VIG, FAIR, DOM, INT, RM and RO are dummy variables taking value of 1 if data are in that category or 0 otherwise.

There might be several possible reasons why the BAG was higher in west (TW) and east zones (TE) of trail (T) and sludge (TS) plots than in the center zone or in the control (C) plots. First, the trail released room for the trees in the TW and TE of the T and TS plots to expand their crowns and root systems and this would allow trees to secure larger supplies of nutrients and water. Second, after some years of thinning the tree crown surface exposed to direct sunlight was consequently greater than that in the center zones and control stand, making possible faster growth.

Growth Related to Vigor Classes

The analysis showed that the BAG of vigorous trees was higher than that of fair trees which grew faster than that of weak trees. Over twelve years, the vigorous trees increased its BAG by 49.58 cm^2 compared to the weak trees. The fair trees increased its BAG by 26.71 cm^2 compared to the weak trees. One possible reason why the BAG of vigorous trees and fair trees were higher than that of weak trees was that the weaker trees needed more energy for maintenance than the healthier ones, whereas their capacity to produce energy was less than the healthier ones.

Growth Related to Crown Classes

During the period of 1981 - 1993, the crown classes showed significant effects on the BAG. The BAG of dominant trees was higher than the BAG of codominant and suppressed trees that grew similarly. This finding might result from the facts that the canopies of the trees responsible for the BAG would be proportional in size to their crown classes.

Growth Related to Stand Density

Table 1 showed that higher number of trees per area (ZNT81) performed negative significant effects on the BAG. This indicated that trees in more dense stands suffered more severe competition for light, water, and nutrients and hence the trees grew slower.

Growth Related to Initial Diameter

The analysis showed that the initial diameter (D81) indicated positive effects on the BAG; the bigger the D81, the higher the BAG. This informed us that most trees in the oak stand were still in their growing stages. The bigger trees would grow faster, because they had more roots to secure the nutrients and bigger leaf areas to produce energy for metabolism.

Growth Related to Species

Tables 1 showed that red maple grew faster than all other species. The BAG of red maple was higher than that of red oak and white oak, whereas red oak grew slower but significantly faster in basal-area than white oak.

CONCLUSIONS AND SUGGESTIONS

Conclusions

During the period of 1981-1993, the tree basal-area growth of the individual trees at the oak site were significantly affected by or correlated with initial tree diameter, initial density of the stand, crown and vigor classes, stand or tree treatments, and species. Sludge influenced significant effect on the tree BAG. Over twelve years sludge treatment increased its tree BAG by 15.53 cm^2 compared to similar non sludged trees. The tree BAG was higher in west and east zones. Over twelve years the access trail increased its tree BAG compared to unthinned trees by 12.32 cm^2 in west zone or by 7.41 cm^2 in east zone.

The tree BAG of vigorous trees were higher than the fair trees and the tree BAG of fair trees were higher than the weak trees. The BAG of dominant trees were higher than the codominant trees and suppressed trees which grew similarly; the BAG of intermediate trees grew the least.

Generally higher stand density was significantly related to lower BAG. and the initial diameter (D81) performed positive effects on the BAG; the bigger the D81, the higher the BAG. The BAG of red maple was higher than the red oak and white oak, while red oak grew slower but significantly faster in basal-area than white oak.

Suggestions

Silvicultural Impact

For operations involving thinning, this study indicated that selecting trees to be either released or cut should include diameter at breast height and species, as well as vigor classes. Because of the similarity of the tree growth among the suppressed and the codominant trees, the crown classes as an indicator of growth becomes less usable. Vigor classes was more usable since the weakest growth of the trees was detectable from the weak class.

Watershed Management Impact

Sludge fertilization to forest was considered important in watershed management practice to represent forest land-management effort to improve the environmental requirement.

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